Small Modular Reactors (SMRs) for Net Zero

- Nuclear small modular reactors (SMRs) are expected to have an essential and increasingly important role to play in supporting net zero targets, particularly for hard-to-abate industrial sectors.
- There are a number of potential benefits to SMRs, ranging from enhanced and passive safety systems to more attractive financing options due to reduced construction schedules, fewer components and smaller plant footprints.
- The first SMRs are expected to be built this decade, followed by accelerated deployment around the world in the 2030s.

OECD
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NUCLEAR ENERGY AGENCY

SMRs are reinventing nuclear energy

Small

SMRs are smaller, both in terms of power output and physical size, than conventional gigawatt-scale nuclear reactors. SMRs are nuclear reactors with power output typically less than 300 megawatts electric (MWe), with some as small as 1-10 MWe.

Modular

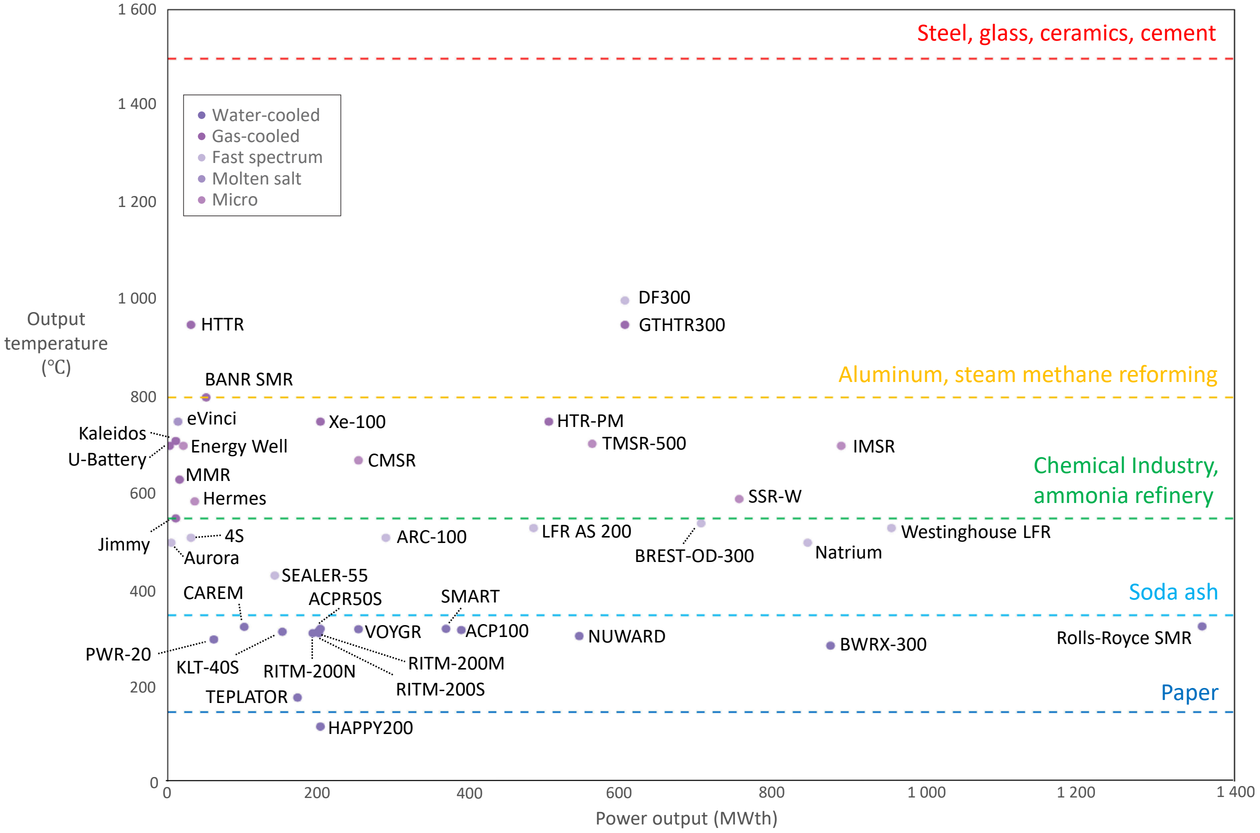
SMRs are designed for modular manufacturing, factory production, portability and scalable deployment.

Reactor

SMRs use nuclear fission reactions to create heat that can be used directly, or to generate electricity. Some SMRs are based on currently deployed technologies, while others are based on so-called “Generation IV” and advanced reactor concepts.

As a class of reactors, SMRs are defined by their smaller size, but there is considerable variety within this class of reactors; they vary by power output, temperature output, technology and fuel cycle. A number of SMRs are based on existing commercially deployed light water technologies, while others are based on advanced design concepts, offering a range of sizes – from 1 MWe to over 300 MWe – and a range of temperatures – from 285°C to more than 850°C to meet the specific energy needs of hard-to-abate industrial sectors.

Figure 1. SMRs – ranges of sizes and temperatures for heat applications



NEA (2023a, 2023b).

The role of SMRs in pathways to net zero

In 2018, the IPCC considered 90 pathways for emission reductions sufficient to limit average global warming to less than 1.5°C (IPCC, 2018). The IPCC found that, on average, these pathways require nuclear energy capacity to increase to 1 160 gigawatts by 2050, from 394 gigawatts in 2020 (IPCC, 2018).

This is ambitious for nuclear energy, but not beyond reach. As illustrated in Figure 2, analysis by the Nuclear Energy Agency (NEA, 2022) finds that this level of capacity can be achieved through a combination of the long-term operation of existing plants, large-scale Generation III new builds and rapid deployment of SMRs. Assuming an SMR build rate that reaches 75 gigawatts per year by 2050, up to 375 gigawatts of installed capacity would be built over the next three decades.

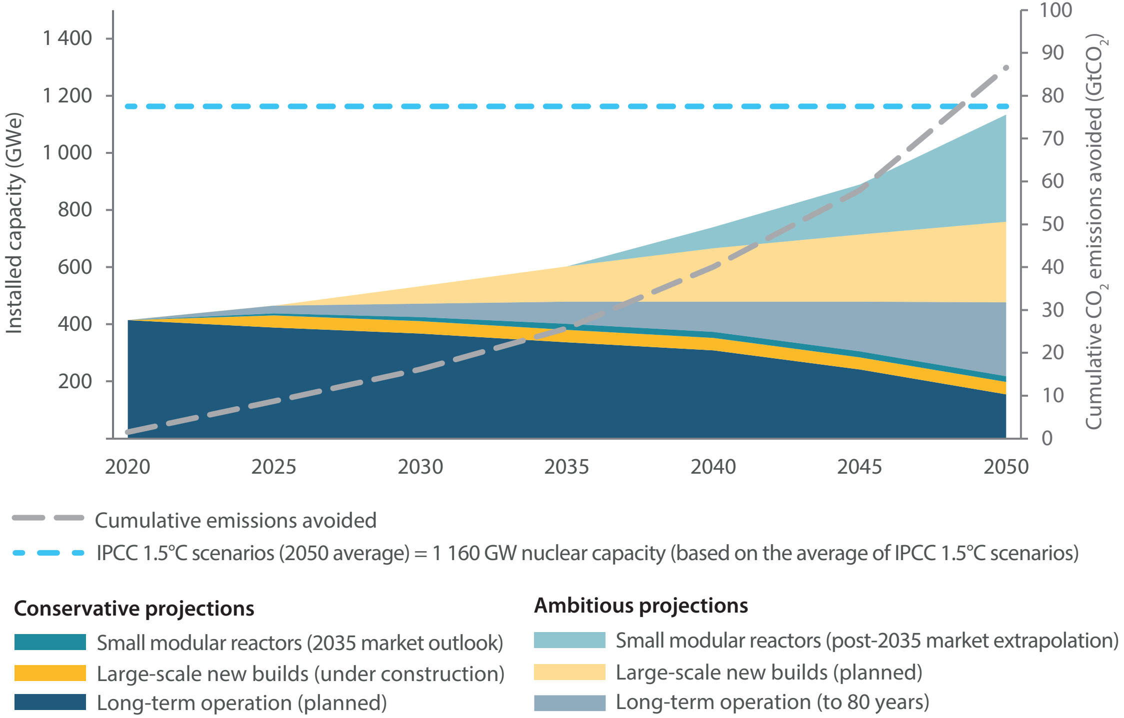
Significant demand for SMRs is expected in hard-to-abate sectors, including for on-grid power to replace coal power plants; off-grid heat and power to replace diesel generators for remote mining operations; high-temperature heat to replace fossil fuel cogeneration in heavy industries such as chemicals processing; and marine propulsion to replace heavy-fuel oil for merchant shipping.

Projected contributions of nuclear energy to cumulative emissions reductions (2020-2050)

Cumulative emissions avoided from…*	…electricity	…heat	…hydrogen	Totals
…long-term operation	38.3	6.7	4.3	49.2
…new builds of large Generation III reactors	16.2	4.2	2.4	22.8
…small modular reactors (SMRs)	9.7	3.6	1.8	15.1
Totals	**64.1**	**14.5**	**8.5**	**87.1**

** All cumulative emissions from 2020 to 2050 are shown in gigatonnes of carbon dioxide ($GtCO_2$).*

Figure 2. Full potential of nuclear contributions to net-zero



Source: NEA (2022).

Box 1: Powering past coal with SMRs

Coal power is still the largest source of electricity generation and emissions globally. However, the coal fleet in OECD countries is slated for retirement due to ageing assets, accelerated decarbonisation policies and dwindling competitiveness. Momentum is growing globally to transition a portion of the global coal fleet to nuclear power, with commitments from utilities in the United States and Central Europe. This presents a significant short-term market opportunity for deploying SMRs in support of climate action.

Due to their size and flexible deployment attributes, SMRs are well-suited to replace coal power plants, many of which have capacities below 500 MWe. Compared to alternatives, SMRs stand out for their dispatchability, energy density and ability to reuse existing infrastructure.

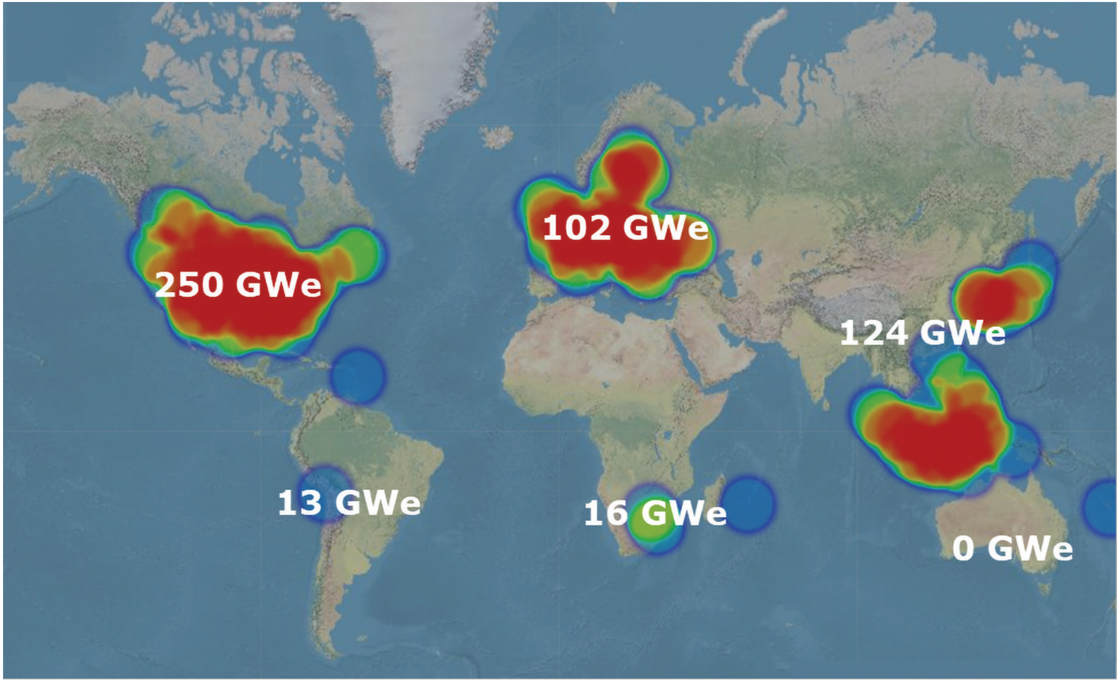
Capital costs will be the primary driver of SMR competitiveness. Beyond serial deployment, cost reductions are possible by reusing existing coal infrastructure. Meanwhile, increasing fuel costs, carbon pricing and stricter environmental regulations are improving the relative competitiveness of SMRs over fossil fuel alternatives. Additionally, SMRs can be part of a diversified technology portfolio that uses nuclear power and renewables to minimise cost and mitigate grid reliability risks. Coal-to-nuclear transitions also bring social benefits and support a just transition for local communities, offering opportunities to retrain and retain the existing coal workforce and to bring additional high-pay jobs during both construction and operation.

The short-term market potential is significant, with around 380 GW of potential market by 2040, mainly driven by retirements in the United States, Europe and Korea. The United States alone represents around 70% of this market.

There are no major technical barriers to replacing coal with SMRs. Utilities should focus on securing water withdrawal and grid transmission permits to maximise site benefits. Siting constraints must be met, particularly regarding seismic conditions, population density and proximity to external hazards. Potential regulatory challenges and legacy coal ash issues can be overcome with proactive planning and investment.

A few large nuclear utilities own over 100 GW of coal capacity globally and could lead as first movers, taking advantage of fleet effects to reduce costs and risks. Establishing industrial consortia among these utilities could further improve the economics and help to enable competitive SMR deployment. Non-traditional players are entering the market as potential off-takers while partnering with vendors and utilities for SMR construction and operation.

Figure 3. Coal replacement with SMR global market potential by 2040 (in GWe)



Source: NEA (forthcoming).

Note: These estimates have been derived using data from the Global Plant Tracker Database.

Box 2: Replacing diesel with SMRs for remote mining – Including critical minerals for the clean energy transition

Mining is a strategic sector in OECD countries to secure domestic supply chain capabilities, support economic growth in rural communities, and enable the clean energy transition. The mining sector represents 2-3% of global CO_2 equivalent emissions, and demand for mining is expected to increase sharply.

Mining companies are exploring the use of SMRs to support the decarbonisation of their activities. In the United States, SMRs are being considered for large grid-connected mines at brownfield sites to support both mining and mineral processing activities. In Poland, efforts are moving forward to deploy SMRs for copper mining and processing.

Off-grid mining offers the most promising near-term opportunities to decarbonise global mining with SMRs due to the high costs associated with operating in remote areas where the current source of energy is diesel generators. In addition, off-grid mines have an average installed power capacity of 16 MWe, suitable for very small SMRs.

The NEA estimates that the market for SMRs for brownfield remote mining could reach more than 2 GWe, primarily concentrated in Australia, Canada, Chile, Indonesia, Russia, the United States and within Sub-Saharan Africa. NEA analysis projects a growing need for remote mining due to increased demand for critical minerals, which are essential to technologies that are required for the clean energy transition. The NEA has found that 16% of critical mineral deposits globally are located more than 20 kilometres from an electricity grid, and that certain specific critical minerals - such as rare earth elements including germanium and niobium - are more commonly found in these remote areas.

In addition to brownfield remote mines, market potential exists for greenfield mines, with about 15% of global mining deposits suitable for remote operations.

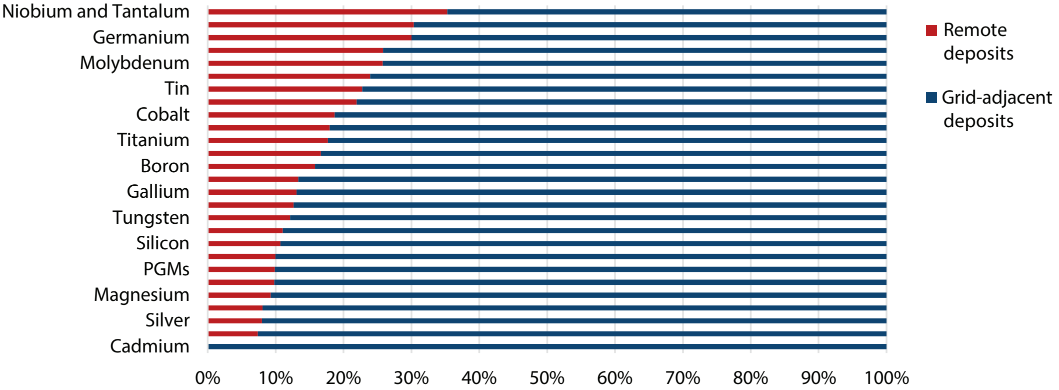
To effectively integrate SMRs into mining operations, policy support measures will be needed to enhance regulatory efficiency. Standardisation across jurisdictions may streamline the licensing process and simplify operational aspects. Transportable SMRs will offer further flexibility.

Figure 4. Existing remote mines that could be replaced by SMRs (total = 2 GWe)

Note:China's mining facilities are under-represented in the data set. Excluding China, the global coverage of the data set is 82%. This method does not accurately capture some self-generating mines (e.g. in Sub-Saharan Africa).

Source: NEA (forthcoming).

Figure 5. Percentage of critical mineral deposits further than 20 kms from the nearest electricity



SMRs' market readiness

Innovation in SMRs is accelerating across the globe.

On the technologies side, several innovative nuclear concepts are under development and nearing commercialisation and deployment. Some are based on traditional light water reactor concepts while others are Generation IV concepts, many of which use new coolants and moderators. Various reactor configurations are also envisaged, with both land-based and marine-based approaches proposed, as well as mobile and multi-module configurations.

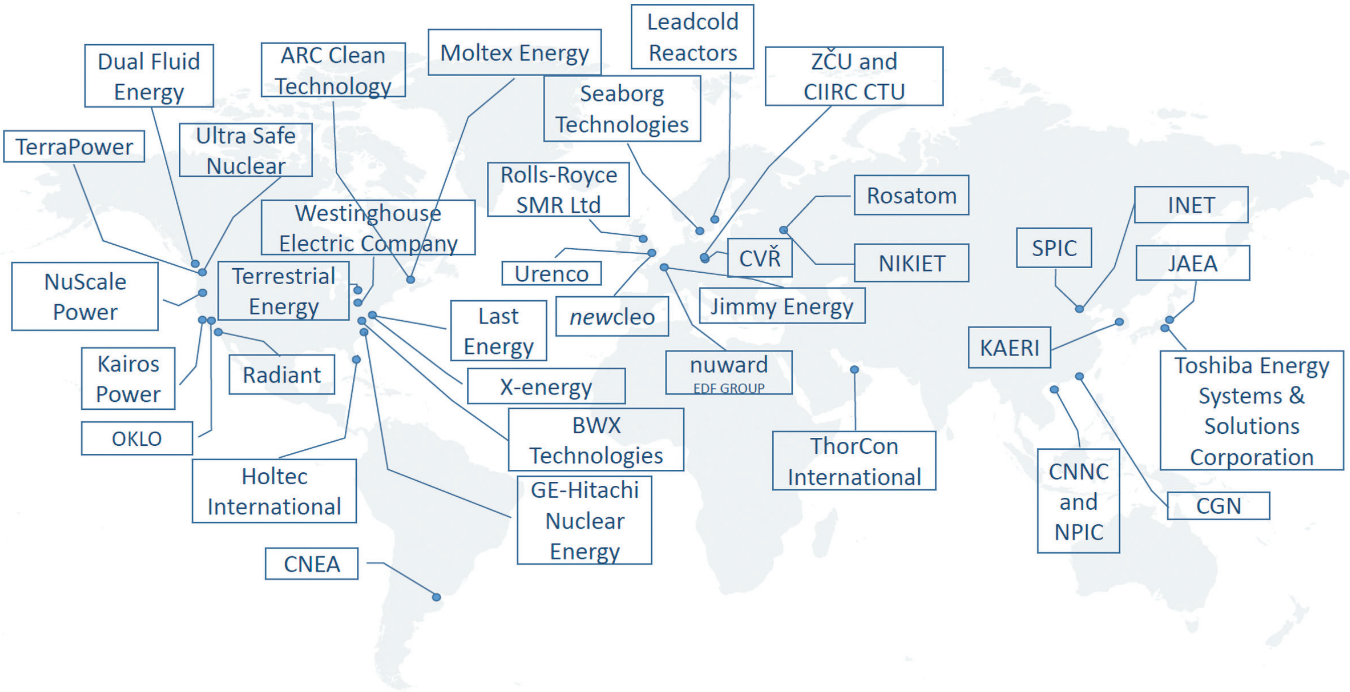
On the demand side, markets are signalling the need for innovative technologies to address energy and climate challenges – including in hard-to-abate industrial sectors. A key market around the world for SMRs and Generation IV reactors is on-grid to replace coal power generation. Beyond on-grid power generation, however, several other markets are signalling interest in SMRs and Generation IV reactors: off-grid heat and power to replace diesel generators in remote regions, including for mining operations; high temperature heat to replace fossil cogeneration in heavy industries such as chemicals processing; and marine propulsion to replace bunker fuel for merchant shipping.

These markets represent emerging – and often disruptive – applications of nuclear energy technologies. Near-term policy and investment decisions will play a key role in shaping overall market outcomes. Public policy and private sector decision makers alike are looking for authoritative assessments of SMRs' power needs, temperature ranges and other operational and technical requirements for specific applications to be able to understand and map market demand.

Beyond technical feasibility, there are several enabling conditions for success to connect supply and demand. Technologies must be a good fit to connect with the specific market applications. Governments and international organisations have a role to play in creating the enabling frameworks – including policies, regulatory readiness and legal aspects. Safe and secure SMR fuel supply chains are essential, as is a responsible plan for the management of the back-end of the fuel cycle. Supply chains more broadly, infrastructure and human resources are all essential enablers. Equally importantly, production costs must be competitive and a mix of public and private financing is required to enable demonstration and deployment of nuclear innovation.

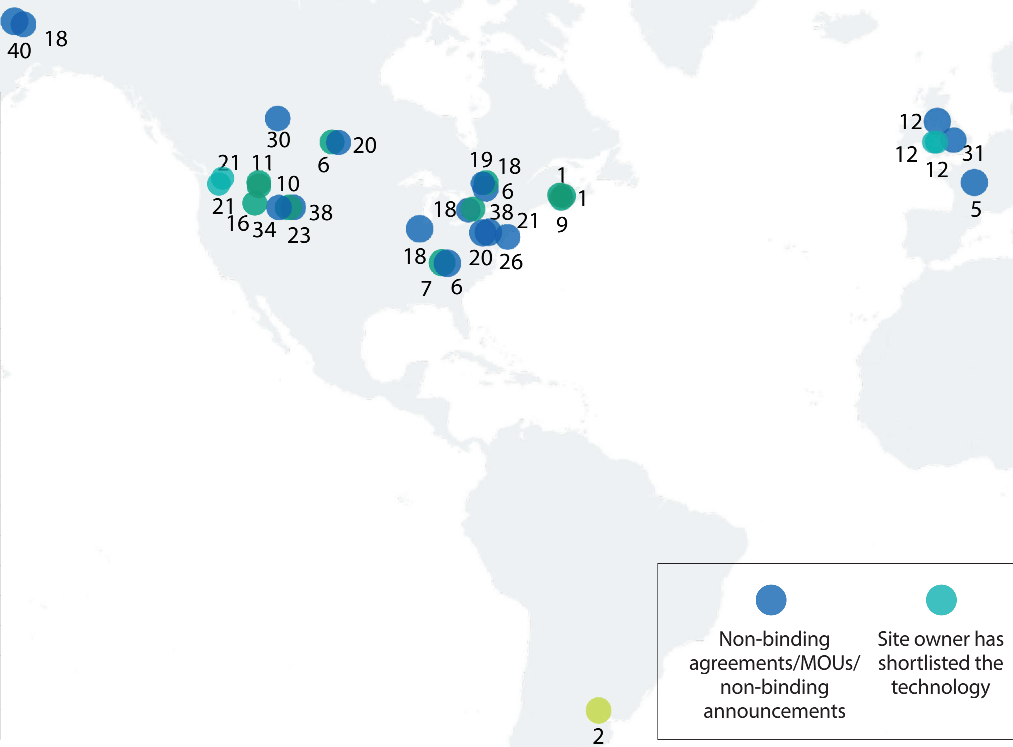
With the right enabling frameworks and public-private partnerships, initial deployment of demonstration reactors is expected this decade, with accelerated deployment around the world to follow in the 2030s.

Figure 6. SMRs under development around the world



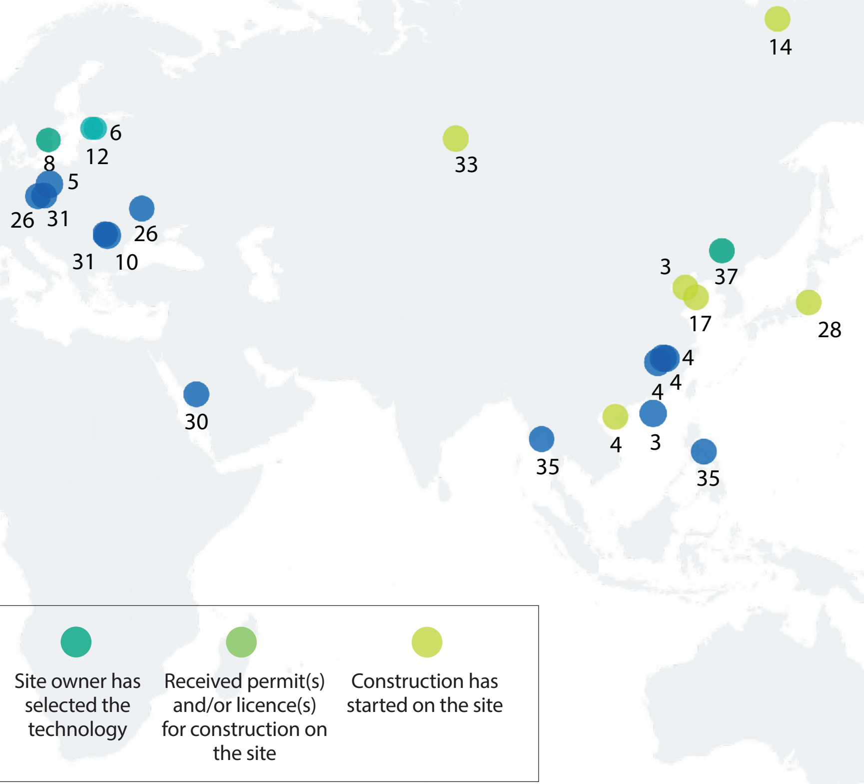
NEA (2023a, 2023b).

Figure 7. SMR siting announcements and progress



1	ARC-100	ARC Clean Technology
2	CAREM	CNEA
3	ACPR50S	CGN
4	ACP100	CNNC and NPIC
5	NUWARD	nuward EDF GROUP
6	BWRX-300	GE-Hitachi Nuclear Energy
7	Hermes	Kairos Power
8	SEALER-55	Leadcold Reactors
9	SSR-Wasteburner	Moltex Energy
10	VOYGR	NuScale Power
11	Aurora	OKLO
12	Rolls-Royce SMR	Rolls-Royce SMR Ltd.
13	KLT-40S	Rosatom
14	RITM-200N	Rosatom
15	RITM-200S	Rosatom
16	Natrium	TerraPower
17	HTR-PM	INET
18	MMR	Ultra Safe Nuclear
19	U-Battery	Urenco
20	eVinci	Westinghouse Electric Company
21	Xe-100	X-energy

NEA (2023a, 2023b).



22	BANR SMR	BWX Technologies
23	Project Pele	BWX Technologies
24	Energy Well	CVŘ
25	DF300	Dual Fluid Energy
26	SMR-160	Holtec International
27	GTHTR300	JAEA
28	HTTR	JAEA
29	Jimmy	Jimmy Energy
30	SMART	KAERI
31	PWR-20	Last Energy
32	LFR AS 200	*newcleo*
33	BREST-OD-300	NIKIET
34	Kaleidos	Radiant
35	RITM-200M	Rosatom
36	CMSR	Seaborg Technologies
37	HAPPY200	SPIC
38	IMSR	Terrestrial Energy
39	TMSR-500	ThorCon International
40	4S	Toshiba Energy Systems & Solutions Corporation
41	Westinghouse LFR	Westinghouse Electric Company
42	TEPLATOR	ZČU and CIIRC CTU

“Accelerating SMRs for Net Zero”: A new NEA initiative

The NEA is launching of the “Accelerating SMRs for Net Zero” initiative at COP28.

The “Accelerating SMRs for Net Zero” initiative capitalises on the NEA’s extensive network of industry leaders, government officials and experts. This initiative aims to conduct authoritative analyses and support collaborative actions, enabling interested decision makers to unlock the full potential of SMRs for climate action. The focus is on establishing practical, solutions-oriented activities supported by a comprehensive plan of collaboration and knowledge exchange. The goal is to inform policy and investment decisions by governments, industry players and the financial sector.

Priorities for 2024 include:

- **Market opportunities**: Producing authoritative assessments of SMR power requirements, temperature ranges and operational specifications to meet decision-making criteria and timelines.
- **Legal, logistical and regulatory challenges**: Addressing issues related to the mobility and transportability of SMRs.
- **Technological and market challenges**: Tackling obstacles associated with sector coupling.
- **Demand signal for fuel cycle investments**: Identifying the need to finance the production of high-assay low-enriched uranium (HALEU) in volumes significant enough to meet a 2027 timeline for first movers.

The NEA anticipates that key findings in these areas and others will be presented and discussed during the inaugural “SMRs for Net Zero” Summit in September 2024.

For more information about the “Accelerating SMRs for Net Zero” initiative, please e-mail: SMR4NZ@oecd-nea.org.

References and further reading

NEA (forthcoming), *NEA SMR Industrial Case Studies*, OECD Publishing, Paris.

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OECD Nuclear Energy Agency (NEA)
46, quai Alphonse Le Gallo
92100 Boulogne-Billancourt, France
Tel.: +33 (0)1 73 21 28 19
nea@oecd-nea.org **www.oecd-nea.org**

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